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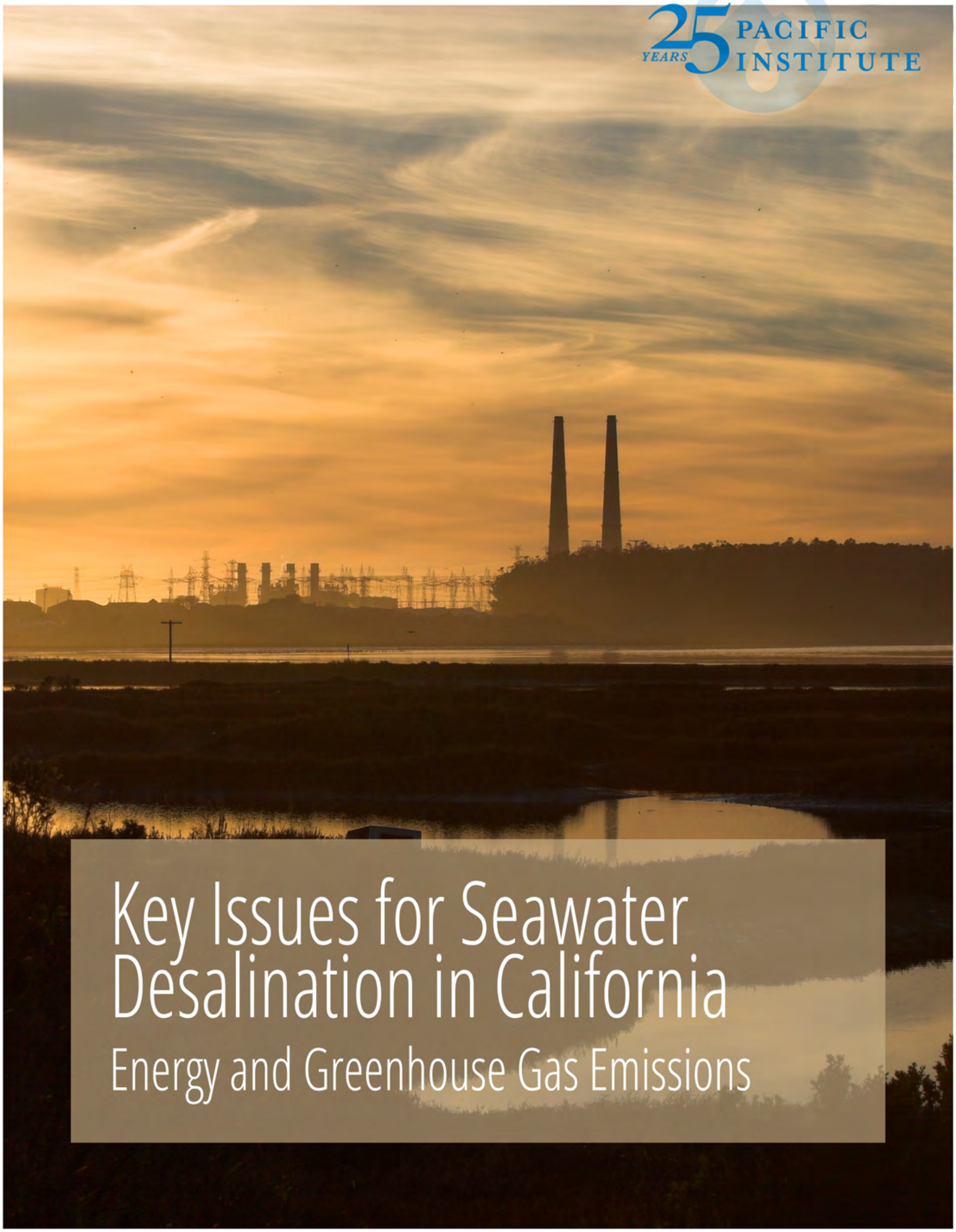

Key Issues for Seawater Desalination in California

Energy and Greenhouse Gas Emissions

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May 2013

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The full report is available online at
www.pacinst.org/reports/desalination_2013/energy

ISBN: 1-893790-49-5   ISBN 13: 978-1-893790-49-0

Designers: Nancy Ross and Paula Luu
Cover photo: iStockphoto.com, © Trudy Karl

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Acknowledgements

This work was generously supported by The David and Lucile Packard Foundation. We thank them for their support. We would also like to thank all those who have offered ideas, data, information, and comments on the report, including (in alphabetical order) Debbie Cook, Kristina Donnelly, Max Gomberg, and Robert Wilkinson. And, last but not least, we would like to thank Nancy Ross and Paula Luu of the Pacific Institute for their help with editing, formatting, and producing the report. All errors and omissions are, of course, our own.

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Executive Summary

In June 2006, the Pacific Institute released *Desalination, With a Grain of Salt*, an assessment of the advantages and disadvantages of seawater desalination for California. At that time, there were 21 active seawater desalination proposals along the California coast. Since then, only one project, a small plant in Sand City, has been permitted and built. A second project, in Carlsbad, recently secured financing and is now under construction. Interest in seawater desalination, however, remains high in California, and many agencies are conducting technical and environmental studies and pilot projects to determine whether to develop full-scale facilities.

Beginning in 2011, the Pacific Institute initiated a new research project on seawater desalination. As part of that effort, we conducted some 25 one-on-one interviews with industry experts, water agencies, community groups, and regulatory agencies to identify some of the key outstanding issues for seawater desalination projects in California. Throughout 2012 and 2013, we are producing a series of research reports that address these issues. The first report, released in July 2012, provided an update of the proposed seawater desalination projects along the coast of California. The second report, released in November 2012, discusses the costs, financing, and risks related to desalination projects.

In this report, the third in the series, we describe the energy requirements of seawater desalination and the associated greenhouse gas emissions. We also evaluate the impact of short-term and long-term energy price variability on the cost of desalinated water. Finally, we describe the current regulations on greenhouse gas emissions in California and identify approaches for mitigating emissions, including strategies used by those who have recently proposed or built new plants in California and Australia. Future reports will evaluate the impacts of seawater desalination on marine life and coastal ecosystems and discuss the permitting process and regulations associated with building new plants in California.

Energy Requirements for Seawater Desalination

Removing the salt from seawater is an energy-intensive process and consumes more energy per gallon than most other water supply and treatment options. On average, desalinations plants use about 15,000 kWh per million gallons of water produced (kWh/MG), or 4.0 kWh per cubic meter (kWh/m^3). We note that these estimates refer to the rated energy use, i.e., the energy required under a standard, fixed set of conditions. The actual energy use may be higher, as actual operating conditions are often not ideal.

The overall energy implications of a seawater desalination project will depend on whether the water produced replaces an existing water supply or provides a new source of water for growth and development. If water from a desalination plant replaces an existing supply, then the additional energy requirements are simply the difference between the energy use of the seawater desalination plant and those of the existing supply. Producing a new source of water, however, increases the total amount of water that must be delivered, used, and disposed of. Thus, the overall energy implications of the desalination project include the energy requirements for the desalination plant plus the energy required to deliver, use, and dispose of the water that is produced. We note that conservation and efficiency, by contrast, can help meet the anticipated needs associated with growth by reducing total water demand while simultaneously maintaining or even reducing total energy use.

Energy requirements for desalination have declined dramatically over the past 40 years due to a variety of technological advances, and desalination designers and researchers are continuously seeking ways to further reduce energy consumption. Despite the potential for future energy use reductions, however, there is a theoretical minimum energy requirement beyond which there are no opportunities for further reductions. Desalination plants are currently operating at 3-4 times the theoretical minimum energy requirements, and despite hope and efforts to reduce the energy cost of desalination, there do not appear to be significant reductions in energy use on the near-term horizon.

Energy Use and Cost

The high energy requirements of seawater desalination raise several concerns, including sensitivity to energy price variability. Energy is the largest single variable cost for a desalination plant, varying from one-third to more than one-half the cost of produced water (Chaudhry 2003). As result, desalination creates or increases the water supplier's exposure to energy price variability. In California, and in other regions dependent on hydropower, electricity prices tend to rise during droughts, when runoff, and thus power production, is constrained and electricity demands are high. Additionally, electricity prices in California are projected to rise by nearly 27% between 2008 and 2020 (in inflation-adjusted dollars) to maintain and replace aging transmission and distribution infrastructure, install advanced metering infrastructure, comply with once-through cooling regulations, meet new demand growth, and increase renewable energy production (CPUC 2009). Rising energy prices will affect the price of all water sources, although they will have a greater impact on those that are the most energy intensive.

Energy Use and Greenhouse Gas Emissions

The high energy requirements of seawater desalination also raise concerns about greenhouse gas emissions. In 2006, California lawmakers passed the *Global Warming Solutions Act*, or Assembly Bill 32 (AB 32), which requires the state to reduce greenhouse gas emissions to 1990 levels by 2020. Thus, the state has committed itself to a program of steadily reducing its greenhouse gas emissions in both the short- and long-term, which includes cutting current emissions and preventing future emissions associated with growth. Action and awareness has, until recently, been uneven and slow to spread to the local level. While the state has directed local and regional water managers to begin considering emissions reductions when selecting water projects, they were not subject to mandatory cuts during the state's first round of emissions reductions. As the state moves forward with its plans to cut carbon emissions further, however, every sector of the economy is likely to come under increased scrutiny by regulators. Desalination – through increased energy use – can cause an increase in greenhouse gas emissions, further contributing to the root cause of climate change and thus running counter to the state's greenhouse gas reduction goals.

While there is "no clear-cut regulatory standard related to energy use and greenhouse gas emissions," (Pankratz 2012) there are a variety of state programs, policies, and agencies that must be considered when developing a desalination project. These include environmental review requirements under the California Environmental Quality Act, the issuance of permits by the Coastal Commission, the Integrated Regional Water Management Planning process, and policies of other state agencies, such as the State Lands Commission and the State Water Resources Control Board. These agencies have increasingly emphasized the importance of planning for climate change and reducing greenhouse gas emissions. While none of these preclude the construction of new desalination plants, the State's mandate to reduce emissions creates an additional planning element that must be addressed.

There is growing interest in reducing or eliminating greenhouse gas emissions by powering desalination with renewables, directly or indirectly, or purchasing carbon offsets. In California, we are unlikely to see desalination plants that are directly powered by renewables in the near future. A more likely scenario is that project developers will pay to develop renewables in other parts of the state that partially or fully offset the energy requirements of the desalination plant. Offsets can also reduce emissions, although caution is required when purchasing offsets, particularly on the voluntary market, to ensure that they are effective, meaningful, and do no harm. A commitment to go "carbon neutral" is laudable; however, project developers should commit to purchasing high-quality offsets from certified sources, and independent parties should verify these claims.

Powering desalination with renewables can reduce or eliminate the greenhouse gas emissions associated with a particular project. This may assuage some concerns about the massive energy requirements of these systems and may help to gain local, and even regulatory, support. But it is important to look at the larger context. Even renewables have a social, economic, and environmental cost, albeit much less than conventional fossil fuels. Furthermore, these renewables could be used to reduce existing emissions, rather than offset new emissions and maintain current greenhouse gas levels. Communities should consider whether there are less energy-intensive options available to meet water demand, such as through conservation and efficiency, water reuse, brackish water desalination, stormwater capture, and rainwater harvesting. We note that energy use is not the only factor that should be used to guide decision making. However, given the increased understanding of the risks of climate change for our water resources, the importance of evaluating and mitigating energy use and greenhouse gas emissions are likely to grow.

1 Introduction

In June 2006, the Pacific Institute released Desalination, With a Grain of Salt, an assessment of the advantages and disadvantages of seawater desalination for California. At that time, there were 21 active seawater desalination proposals along the California coast. Since then, only one project, a small plant in Sand City, has been permitted and built. A second project, in Carlsbad, has recently secured financing and is now under construction. Interest in seawater desalination, however, remains high in California, and many agencies are conducting technical and environmental studies and pilot projects to determine whether to develop full-scale facilities.

In 2011, the Pacific Institute began new research on seawater desalination. As part of that effort, we conducted some 25 one-on-one interviews with industry experts, environmental and community groups, and staff of water agencies and regulatory agencies to identify some of the key outstanding issues for seawater desalination projects in California. This is the third in a series of research reports that address these issues. The first report, released in July 2012, describes the 19 proposed projects along the California coast. The second report, released in November 2012, discusses the costs, financing, and risks related to desalination projects.

In this report, we describe the energy requirements of seawater desalination and the associated greenhouse gas emissions. We also evaluate the impact of short-term and long-term energy price variability on the cost of desalinated water. Finally, we describe current regulations on greenhouse gas emissions in California and identify approaches for mitigating emissions, including strategies used by those who have recently proposed or built new plants in California and Australia. Future reports will evaluate the impacts of seawater desalination on marine life and coastal ecosystems, and discuss the permitting process and regulations associated with building new plants in California.

Energy Requirements of Seawater Desalination

Removing the salt from seawater is an energy-intensive process and consumes more energy per gallon than most other water supply and treatment options. The energy requirements for desalination are determined by several factors related to the site and design of the plant. Design considerations include the desalination technology employed, whether energy recovery devices are used, and the rate of recovery, e.g., the volume of freshwater produced per volume of seawater taken into the plant. Site-specific factors include source-water salinity and temperature and the desired quality of the product water.

Table 1 summarizes energy use at 15 large reverse osmosis (RO) seawater desalination plants that have been constructed since 2005. On average, these plants use about 15,000 kWh per million gallons of water produced (kWh/MG), or 4.0 kWh per cubic meter (kWh/m^3).[1] We note that these estimates refer to the rated energy use, i.e., the energy required under a standard, fixed set of conditions. The actual energy use may be higher, as actual operating conditions are often not ideal. Membrane fouling, for example, can increase the amount of energy required to desalinate water.

As shown in Figure 1, the reverse osmosis process accounts for nearly 70% of the total energy use, while pre- and post-treatment and pumping each account for 13%. Another 7% of energy is used to pump water from the ocean to the plant.

Table 1. Energy Requirements (kWh/MG) for Seawater Desalination Plants Using Reverse Osmosis

Plant	Energy Requirements (kWh/MG)	Energy Requirements (kWh/m3)	Facility Capacity (m3/day)	Date Contracted
Kwinana, Perth, Australia	14,000	3.60	140,000	2005
China	16,000	4.10	35,000	2005
Egypt	15,000	4.00	1,000	2005
Raleigh IWSPP, Saudi Arabia	18,000	4.80	230,000	2005
Rambla Morales, Spain	12,000	3.30	60,000	2005
Valdelentisco, Spain	17,000	4.40	140,000	2005
Khor Fakhan Power Plant, UAE	15,000	4.00	23,000	2005
Aruba	15,000	4.00	8,000	2006
Gold Coast, Australia	14,000	3.60	130,000	2006
Israel (Hadera)	17,000	4.50	273,000	2006
Bonaire, Dutch Antilles	15,000	4.00	8,000	2006
Alicante II, Spain	14,000	3.70	65,000	2006
Fujairah 1, UAE	18,000	4.80	170,000	2006
Caofeidian, China	15,000	4.00	50,000	2009
Ashkelon Expansion, Israel	14,000	3.80	41,000	2009

Note: All numbers rounded to two significant figures.
Source: GWI 2010

[1] In this report, we use the units of kWh to refer to units of electrical energy. This is also sometimes referred to as kWh_e. By contrast, kWh_{th} represent a unit of heat and does not account for efficiency losses in the conversion of heat to electricity; e.g., for a typical power plant operating at 33% efficiency, there are 3 kWh_{th} per kWh_e.

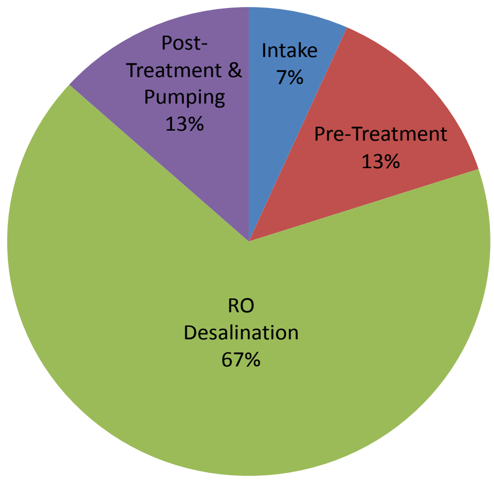

Figure 1. Energy Use for Various Elements of the Desalination Process
Source: Kennedy/Jenks Consultants 2011

Over the lifetime of a desalination plant, different forms of energy – electricity, gasoline, and other fuels – are required to construct, operate, maintain, and eventually decommission the plant. A full lifecycle analysis of desalination energy use would also include energy for the production, transport, and disposal of chemicals, membranes, and others materials that are consumed over the plant's operational life. Accounting for all of these energy uses is beyond the scope of this paper. However, life-cycle analyses have been conducted for seawater desalination plants, and these suggest that operations dominate the life-cycle energy use, accounting for about 95% of total energy use (Stokes and Horvath 2006, Stokes and Horvath 2008).

Energy Use Comparisons

The water sector in California is a large user of electricity and natural gas. The California Energy Commission (CEC) (2005) estimates that capturing, transporting, and treating water and wastewater uses approximately 5% of the electrical energy and 1% of the natural gas consumed in the state (Table 1). Water-related energy use in homes, businesses, and institutions accounts for an additional 13% of the state's electricity and 31% of the state's natural gas usage. In total, approximately 19% and 32% of the state's electricity and natural gas usage, respectively, is water related. Nearly three-quarters of the electricity and almost all of the natural gas use occurs inside homes and businesses, mostly for heating. We note that recent studies suggest that the CEC estimates may be low. An analysis by GEI Consultants and Navigant Consulting (2010), for example, estimates that the energy requirements for water and wastewater systems are 8%, higher than the 5% estimate by the CEC. Additional effort is needed to refine these estimates.

Table 2. Estimated Water-related Electricity and Natural Gas Consumption in 2001

	Electricity (GWh)	Natural Gas (million therms)
Water Supply and Treatment	10,742 (4%)	19 (<1%)
End Uses	35,259 (13%)	4,238 (31%)
Wastewater Treatment	2,012 (<1%)	27 (<1%)
Total Water-Related Energy Use	48,012 (19%)	4,284 (32%)
Total California Energy Use	250,494	13,571

Source: CEC 2005
Note: Numbers may not add up due to rounding.

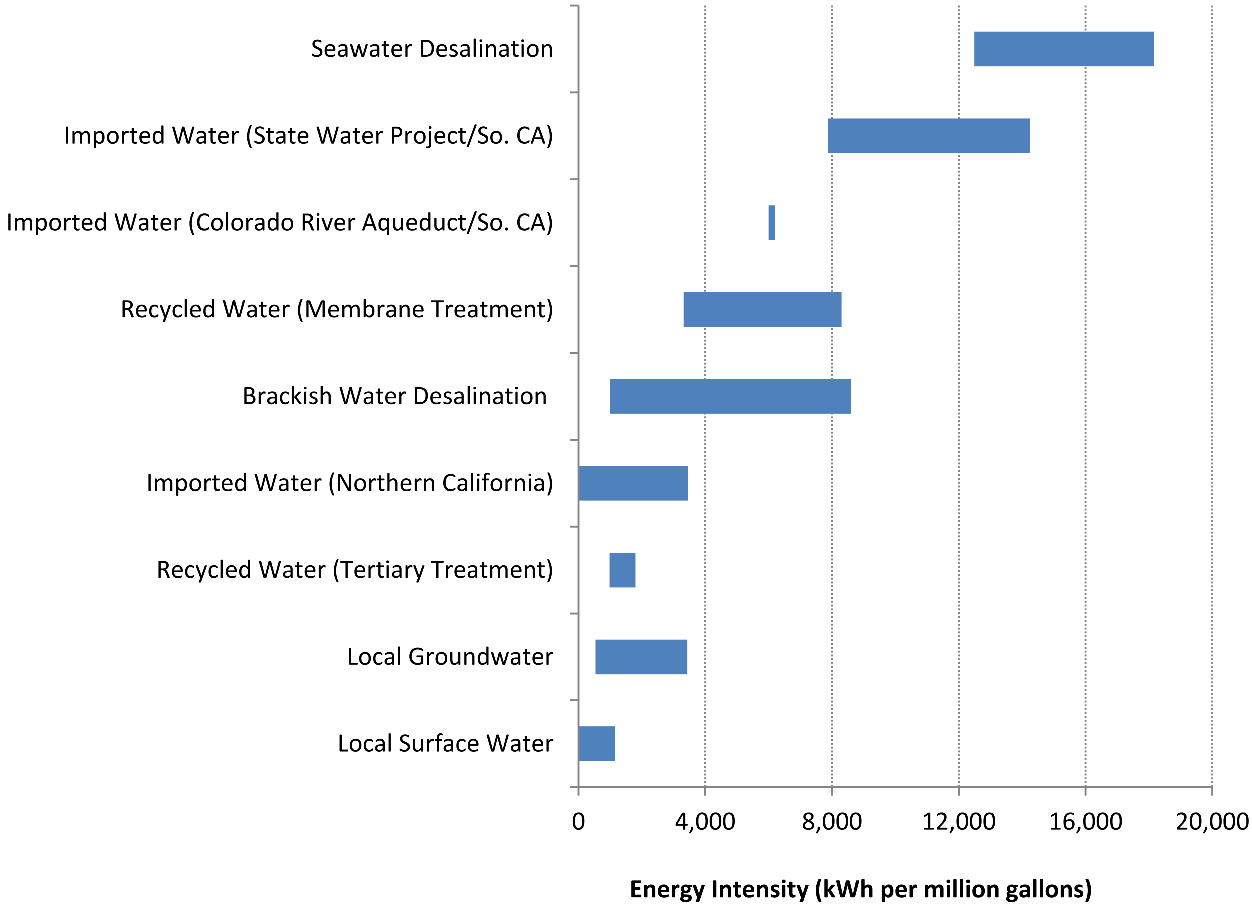

Figure 2. Comparison of the Energy Intensity of California Water Supplies

Notes: Estimates for local and imported water sources shown here do not include treatment, while those for desalination and recycled water include treatment. Typical treatment requires less than 500 kWh per million gallons. The upper range of imported water for Northern California is based on the energy requirements of the State Water Project along the South Bay Aqueduct. Energy requirements for recycled water refer to the energy required to bring the wastewater that would have been discharged to recycled water standards. Estimates for brackish water desalination are based on a salinity range of 600 – 7,000 mg/l.

Sources: Veerapaneni et al. 2011; GWI 2010; Cooley et al. 2012; GEI Consultants/Navigant Consulting, Inc. 2010

Seawater desalination is considerably more energy-intensive than most other water supply options. Figure 2 shows the energy intensity, in kilowatt-hours (kWh) per million gallons, of various water supply options. Local sources of groundwater and surface water are among the least energy-intensive options available. The energy requirements for recycled water vary, depending on the level of treatment required to meet the water quality of a desired end use.[2] Wastewater that will be reused for irrigation and other non-potable uses typically undergoes tertiary treatment and has an energy intensity of 1,000 – 1,800 kWh per million gallons (0.26 – 0.48 kWh/m^3). Wastewater that will be used to recharge aquifers may undergo membrane treatment, with an energy requirement of 3,300 – 8,300 kWh per million gallons (0.87 – 2.2 kWh/m^3).

Imported water can be especially energy intensive, depending on the distance the water is moved and the change in elevation. Some imported water

[2] Energy requirements for recycled water refer to the energy required to bring the wastewater that would have been discharged to recycled water standards. If wastewater is treated to primary or secondary standards before discharge, then additional treatment is required to bring it to reuse standards, and the energy required for that additional treatment is attributed to the recycled water.

systems use little energy and may even generate it. Examples in California include the Los Angeles Aqueduct, San Francisco's Hetch Hetchy Aqueduc and East Bay Municipal Utility District's Mokelumne Aqueduct. Most water systems that convey water to Southern California, however, use large amounts of energy. Water imported through the Colorado River Aqueduct, for example, requires about 6,100 kWh per million gallons (1.6 kWh/m^3). Energy requirements for the State Water Project, which pumps water from the Sacramento-San Joaquin Delta to Southern California, are even higher, ranging from 7,900 – 14,000 kWh per million gallons (2.1 – 3.7 kWh/m^3).

In comparison, energy requirements for seawater desalination range from 12,000 – 18,000 kWh per million gallons (3.2 – 4.8 kWh/m^3) (Table 1). Seawater desalination is thus considerably more energy intensive than almost every other water supply option available. While there are some inland areas, such as in parts of Riverside County, where the energy intensity of imported water is comparable to that of seawater desalination, these are in relatively limited areas with a small population.

The overall energy implications of a seawater desalination project will depend on whether the water produced replaces an existing water supply or provides a new source of water for growth and development. If water from a desalination plant replaces an existing supply, then the additional energy requirements are simply the difference between the energy use of the seawater desalination plant and those of the existing supply. Producing a new source of water, however, increases the total amount of water that must be delivered, used, and disposed of. Thus, the overall energy implications of the desalination project include the energy requirements for the desalination plant plus the energy required to deliver, use, and dispose of the water that is produced. We note that conservation and efficiency, by contrast, can help meet the anticipated needs associated with growth and development by reducing total water demand while simultaneously maintaining or even reducing total energy use (Cooley et al. 2010).

Energy Reduction Strategies

Energy requirements for desalination have declined substantially over the past 40 years due to a variety of technological advances. Membranes, for example, have advanced considerably over the past two decades, and most new plants use membrane-based technology (e.g., reverse osmosis) that are less energy-intensive than thermal-based technology (e.g., multi-stage flash distillation). Additionally, energy recovery devices are now standard in newer plants and can capture 76% to 96% of the energy contained within the brine concentrate (NRC 2008), further reducing energy requirements (Box 1). Other advances that have reduced energy requirements include higher-permeability membranes and more efficient pumps (Fritzmann et al. 2007). In looking to further reductions, the National Research Council notes that some of the most promising research is focused on alternative desalination technologies, such as forward osmosis (Box 2) and membrane distillation; hybrid membrane-thermal desalination; improved energy recovery devices; and utilization of waste or low-grade heat (NRC 2008).

Desalination designers and researchers are continuously seeking ways to further reduce energy consumption. This research has been supported by state and federal funding as well as by the private sector. In a recent industry-led initiative, the International Desalination Association created an Energy Task Force in order to develop a framework for reducing energy consumption by 20% for all major seawater desalination processes. The Task Force, which includes engineers, consultants, and researchers from governments, corporations, and academia, is working to establish a benchmark of energy use at existing plants and a preliminary methodology for reporting energy consumption. The Task Force is also developing guidelines for reducing energy use and exploring the further development and use of alternative energy sources and hybrid processes that combine thermal and membrane desalination technologies (Stedman 2012). The Task Force held its first meeting in January 2013 and will complete work in 2015.

Despite the potential for future energy use reductions, however, there is a theoretical minimum energy requirement beyond which there are no opportunities for further reductions. The theoretical minimum amount of energy required to remove salt from seawater using reverse osmosis at 25°C is around 3,400 kWh per million gallons (0.90 kWh/m^3) for 40% recovery (NRC 2008).[3] Note that this estimate is for the removal of salts from seawater and does not include the energy required to pump water to the facility, pre- and post-treatment, and deliver water to the distribution system. Desalination plants are currently operating at 3-4 times the theoretical minimum energy requirements. The Affordable Desalination Collaboration, a California-based group, has constructed a bench-scale plant that has demonstrated energy intensities ranging from 6,800 to 8,200 kWh per million gallons (1.8 – 2.2 kWh/m^3) for the reverse-osmosis process alone using commercially available energy recovery devices, efficient pumps, and low-energy membranes; the total energy use, including water intake, pre-filtration, and permeate treatment, for a 50 MGD plant would be about 50% higher (WateReuse Association 2011). These results, while promising, are for a demonstration plant and have not yet been achieved at a full-scale commercial plant.

Box 1: What are Energy Recovery Devices and How Do They Work?

In reverse-osmosis desalination systems, seawater is pressurized using high-pressure pumps. The pressurized water is forced through the membrane, producing low-pressure freshwater and high-pressure brine. Energy-recovery devices have been developed to re-capture some of the hydraulic energy of the high-pressure brine.

Energy-recovery devices have been employed in seawater reverse-osmosis plants since the 1980s. Early devices – Pelton and Francis turbines and hydraulic turbochargers – were centrifugal devices that used hydraulic energy in the brine to power a turbine. The turbine would then spin a shaft that would power the high-pressure pumps used to move seawater into the desalination plant. The overall efficiency of the systems is determined by the combined efficiency of the turbine and the high-pressure pump. In general, centrifugal devices have a maximum energy recovery rate of 80% (Stover 2007).

Today, these mechanical turbines are increasingly being replaced by more efficient devices called isobaric energy-recovery devices. Isobaric energy-recovery devices directly transfer pressure from the brine to the incoming seawater and can recover up to 98% of the energy in the waste stream (Grondhuis n.d.). While centrifugal devices are usually optimized for a relatively narrow range of flow- and pressure-operating conditions, isobaric energy-recovery devices operate at high efficiency over a much broader range of conditions. While some mixing of brine and feed water occurs, these shortcomings are offset by reductions in energy use (Grondhuis n.d.).

[3] The recovery rate is the volume of freshwater produced per volume of seawater taken into the plant. Typical recovery rates for a seawater desalination plant are 40-50%. The minimum energy requirements increase at higher recovery rates.

Box 2: Forward Osmosis

Under ambient conditions, water will naturally diffuse through a semi-permeable membrane from a solution of lower concentration to a solution with a higher concentration. That is, if freshwater and saline water are separated by a membrane, then the freshwater will naturally move across the membrane to dilute the saline water so that the salt concentrations of the two solutions are equal. This process is referred to as *osmosis*. The pressure required to stop the flow of water across the membrane is referred to as osmotic pressure. Reverse osmosis plants apply pressure to the saline water in excess of the osmotic pressure, thereby forcing freshwater to flow against its natural tendency, e.g., from a solution of high concentration to low concentration.

Forward osmosis is a process that also uses a semipermeable membrane to separate water from dissolved solutes. Forward osmosis uses a "draw solution" with a relatively high solute concentration (compared to the feedwater) that allows the natural movement of water across the membrane (Figure B2-1). Once equilibrium has been achieved, the constituents of the draw solution can be separated to produce pure water, and the draw solution can be reused. Drinking water forward osmosis systems are not yet commercially viable (Qin et al. 2012).

In general, commercial forward osmosis systems are expected to have lower operational and maintenance costs than reverse osmosis systems. With forward osmosis, energy use and fouling are greatly reduced as the water is drawn, rather than forced, through the membrane (Cath et al. 2006). Moreover, membrane fouling reduces treatment efficiency in a typical reverse osmosis system, something that is avoided in an unpressurized forward osmosis system. Additionally, unpressurized systems are less expensive to build and maintain.

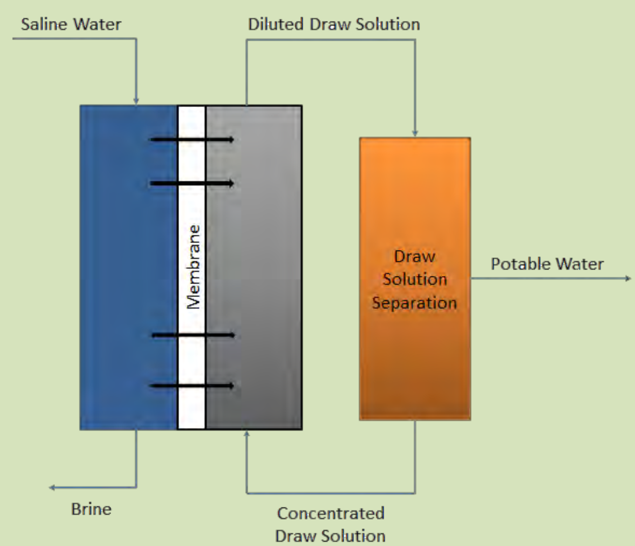

Figure B2-1. Forward Osmosis Schematic

Achieving commercial-scale production of forward osmosis desalination has been limited by the ability to identify a suitable membrane and draw solution. The draw solution must have two key characteristics: a higher osmotic potential than the feedwater and characteristics that permit the freshwater to be separated from the draw solute with low energy input (Li et al. 2011a). Draw solutes that have been studied include carbon dioxide and ammonia, sugar, and ethanol (Li et al. 2011b). The membranes must be chemically stable and have a high flow rate and solute rejection capacity (D&WR 2010). The only membrane suitable for forward osmosis that is currently commercially available, however, cannot tolerate a wide pH range of the draw solution (Qin et al. 2012).

Forward osmosis is being researched and implemented in laboratories and small, pilot-scale facilities. For example, Modern Water built the world's first near-commercial forward osmosis desalination plants in Gibraltar and Oman, producing 18 and 100 cubic meters per day, respectively (D&WR 2012a; Thompson and Nicoll 2011; desalination.com n.d.). Independent research on the cost, effectiveness, and flexibility of these systems has not yet been conducted.

2

Energy Use and Cost

Desalinated seawater is an energy-intensive water source and relying on it increases the water supplier's exposure to near- and long-term variability in energy prices. Energy is the largest single variable cost for a desalination plant, varying from one-third to more than one-half of the cost of produced water (Chaudhry 2003). The National Research Council (2008) reports that energy accounts for 36% of the typical water costs of a reverse osmosis plant, with the remainder from other operation and maintenance expenses and fixed charges.[4] Energy requirements for thermal plants are even higher, accounting for nearly 60% of the typical cost of produced water for large thermal seawater desalination plant (Wangnick 2002). At these percentages, a 25% increase in energy cost would increase the cost of produced water by 9% and 15% for reverse osmosis and thermal plants, respectively. Unless there is a way to greatly reduce the actual amount of energy used in desalination processes, the share of desalination costs attributable to energy will rise as energy prices increase.

Energy prices exhibit both near-term and long-term variability. Many factors can affect near-term energy prices, including energy demand and fuel prices. To determine whether dry conditions affect electricity prices, we analyzed historical electricity prices and precipitation in California. Our analysis found that there is a negative correlation between precipitation and electricity prices for four out of six of California's major utilities (Table 3). At each of these, lower-than-average precipitation in the previous two years is associated with higher electricity prices. Thus, electricity costs more in drier years. This makes sense given that relatively inexpensive hydropower is an important source of electricity in California and that less precipitation means that less water is available to generate hydroelectricity. In response, utilities must purchase more electricity on the market or generate it from more expensive coal and natural gas power plants.

The relationship between precipitation and electricity price varies among the utilities and is stronger for those utilities more dependent on hydroelectricity. For PG&E, for example, 69% of the variance in energy prices can be explained by precipitation, as indicated by a correlation coefficient of -0.69 (Table 3). PG&E's retail electricity prices closely track California's total two-year precipitation, as shown in Figure 3. Indeed, 22% of PG&E's generation portfolio comes from hydroelectricity (PG&E 2012). By contrast, only about 0.1% of SDG&E's generation portfolio comes from hydropower (SDG&E 2013), and thus no statistically significant relationship was found between precipitation and electricity prices.

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[4] This estimate is based on an energy cost of $0.07 per kilowatt-hour, a 5-year membrane life, a 5% nominal interest rate, and a 25-year depreciation period.

Table 3. Correlation between Precipitation and Retail Energy Price for Six Major California Utilities

	Direction of Correlation	Correlation Coefficient	Pearson's R P-value	Mann-Kendall P-value
Pacific Gas and Electric (PG&E)	↓	-0.69	<0.001	<0.001
Southern California Edison (SCE)	↓	-0.49	0.005	0.003
San Diego Gas and Electric (SDG&E)	--*	+0.31	0.05	0.32
Los Angeles Department of Water and Power (LADWP)	↓	-0.38	0.02	0.03*
Sacramento Municipal Utility District (SMUD)	↓	-0.59	<0.001	<0.001
Burbank-Glendale-Pasadena (BGP)	--*	-0.25	0.15	0.10

Note: Two different statistical methods were used to test the significance of the relationship between precipitation and electricity price: Pearson's correlation coefficient test and the non-parametric Mann-Kendall test. We used a two-tailed hypothesis test at the 95% confidence level. The null hypothesis is that there is no relationship between precipitation and energy price. When the test gives a probability (or P-value) of less than 0.025, we reject the null hypothesis and conclude that there is evidence that precipitation and energy prices are correlated. Alternatively, when the P-value is greater than 0.025, we fail to reject the null hypothesis and find that there is not enough evidence for a relationship between precipitation and energy price. In the table, "--*"means that the relationship is not significant at the 95% confidence level.

These results suggest that desalination plants served by energy utilities dependent on hydropower may be more vulnerable to short-term energy price increases associated with dry conditions in California. If the desalination plant is operated more in dry years than in wet years, the average cost per unit of water produced will be higher than the estimated cost based on the average electricity price. This is because more units of electricity will be purchased at prices higher than average (during drought) than at prices lower than average (during wet years). This can be especially challenging during a drought, when revenues may be down due to reduced water sales. Since desalination plants will likely be operated at peak output during drought, unexpectedly high costs could amplify revenue instability already experienced by water suppliers.

It is important to note that water from a desalination plant may be worth more in a drought year because other sources of water will be limited, thereby justifying the higher cost. Thus, building a desalination plant may reduce a water utility's exposure to water reliability risks at the added expense of an increase in exposure to energy price risk. Project developers may pay an energy or project developer to hedge against this uncertainty, e.g., through a long-term energy purchase contract or through on-site energy production from sources with less variability. such as solar electric. The hedging options, however, may increase the overall cost. In any case, energy price uncertainty creates costs that should be incorporated into any estimate of project cost.

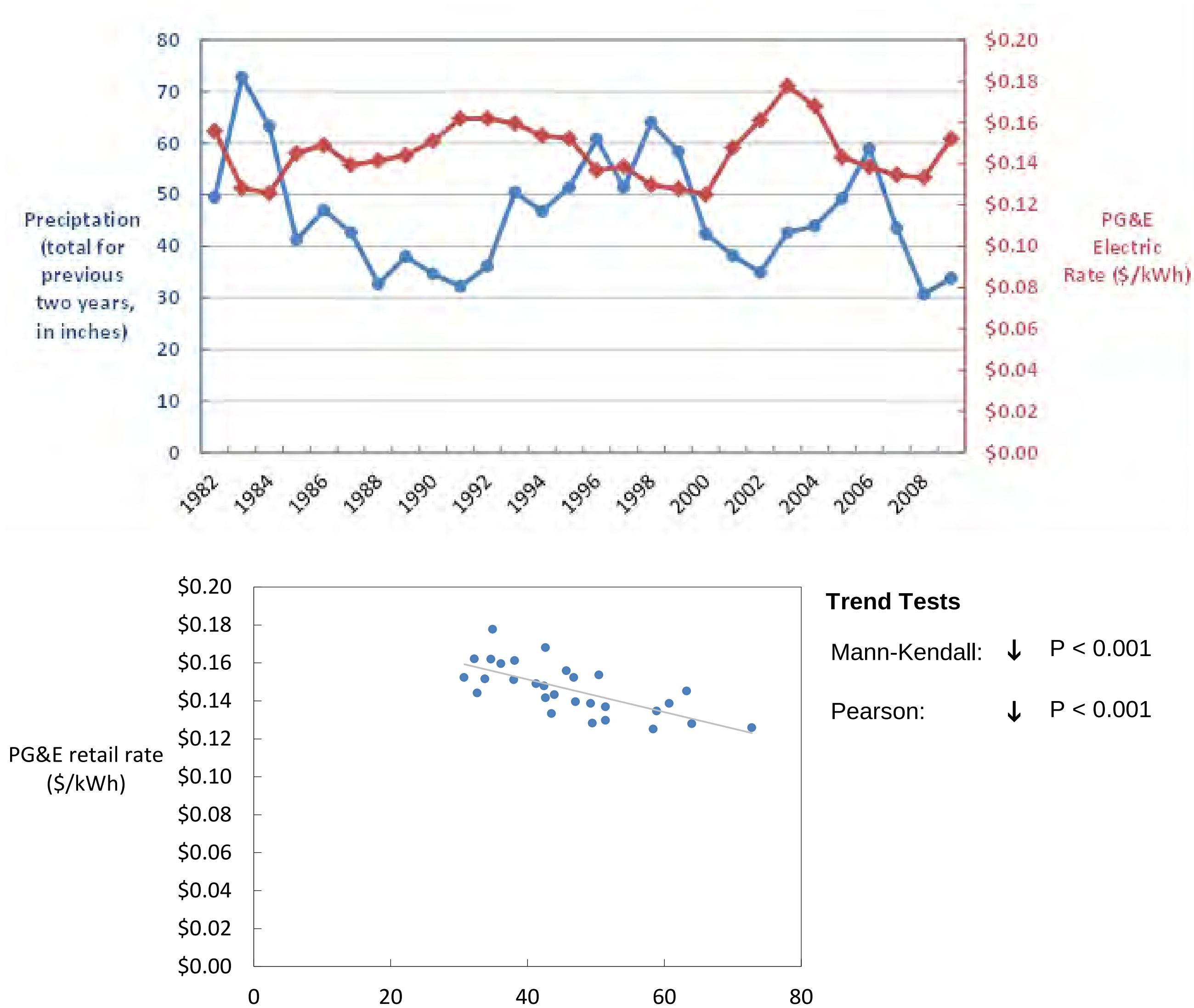

Figure 3. Time Series (above) and Scatterplot (below) of PG&E's Retail Energy Rates Versus California's Two-Year Precipitation Totals for the Two Previous Years, 1982–2010

Source: Statewide precipitation estimates are from Abatzoglou (2009). Energy price data from a dataset published by the California Energy Commission ("Statewide Electricity Rates by Utility, Class and other," Excel workbook, http://energyalmanac.ca.gov/electricity/Electricity_Rates_Combined.xls)

In addition to near-term variability, energy prices exhibit long-term variability. Future electricity prices in California remain uncertain but are likely to rise for several reasons. For example, the San Onofre Nuclear Generating Plant has been shut down for more than a year, and there is some uncertainty about whether it will be repaired or retired and replaced, and at what cost. Electricity infrastructure must be maintained, and new infrastructure may be needed. Additionally, California, like many states, has established a Renewables Portfolio Standard that requires investor-owned utilities, electric service providers, and community choice aggregators to source 33% of their power from eligible renewable energy resources by 2020.[5]

The future cost of these renewables, and even fossil fuels, is uncertain. The California Public Utilities Commission estimates that electricity prices will rise by nearly 27% in inflation-adjusted dollars from 2008 to 2020, driven by the need to maintain and replace aging transmission and distribution infrastructure, install advanced metering infrastructure, comply with once-through cooling regulations and the Renewable Portfolio Standard, and meet new demand growth (CPUC 2009). We note, however, that the price of renewables and natural gas has declined considerably since the CPUC developed these estimates and that the actual cost increase may be less than originally anticipated. Project developers should periodically examine long-term energy price projections to appropriately capture impacts on desalination costs.

[5] Eligible renewable energy sources include biomass, solar thermal, photovoltaic, wind, geothermal, fuel cells using renewable fuels, small hydroelectric generation of 30 megawatts or less, digester gas, municipal solid waste conversion, landfill gas, ocean wave, ocean thermal, or tidal current.

3 Energy Use and Greenhouse Gas Emissions

Seawater desalination, through its energy use and other processes, contributes to the emissions of air pollutants and greenhouse gases. The high energy requirements of seawater desalination raise concerns about the associated greenhouse gas emissions. In this section, we discuss how regulators are handling the challenge of greenhouse gas (GHG) emissions from desalination plants and examine the role these emissions play in obtaining permits and approvals from state and federal regulators. We look at the laws, policies, and programs related to GHG emissions, and what effect these may have on proposed desalination plants. Finally, we discuss how proponents of existing and proposed desalination plants are handling the issue, including efforts to reduce their GHG emissions.

Background on Carbon Emissions in California

In 2006, California lawmakers passed the *Global Warming Solutions Act*, or Assembly Bill 32 (AB 32). AB 32 requires the state, the 14th largest emitter of greenhouse gases in the world (ARB 2008), to reduce greenhouse gas emissions to 1990 levels by 2020. Thus, the state has committed itself to a program of steadily reducing its greenhouse gas emissions in both the short- and long-term, which includes cutting current emissions and preventing future emissions associated with growth. According to the California Air Resources Board (ARB), which has been tasked with implementing the GHG reduction law, "reducing greenhouse gas emissions to 1990 levels means cutting approximately 30 percent from business-as-usual emission levels projected for 2020, or about 15 percent from today's levels" (ARB 2008). ARB plans to achieve these reductions through a combination of energy efficiency, clean energy, clean transportation, and market-based programs.

Under AB 32, the state must reduce emissions to 1990 levels, i.e., 427 million metric tonnes of carbon dioxide equivalent ($MMTCO_2e$), by 2020 (ARB 2008, 5). The roadmap for achieving these reductions was laid out by ARB in 2008 in its *Climate Change Scoping Plan*. ARB originally estimated the reductions needed based on emissions data for 2002–2004. Emissions during that period were 469 $MMTCO_2e$. The authors envisioned a continually growing population and strong economic growth, and the challenge for the state was to encourage "clean development" to avoid the huge emissions increases that would occur under a "business-as-usual" scenario. To accommodate this future growth while still meeting the targets set forth in AB 32, the Scoping Plan called for a reduction of 169 $MMTCO_2e$ from several required measures and an additional 44 $MMTCO_2e$ from "other recommended measures."

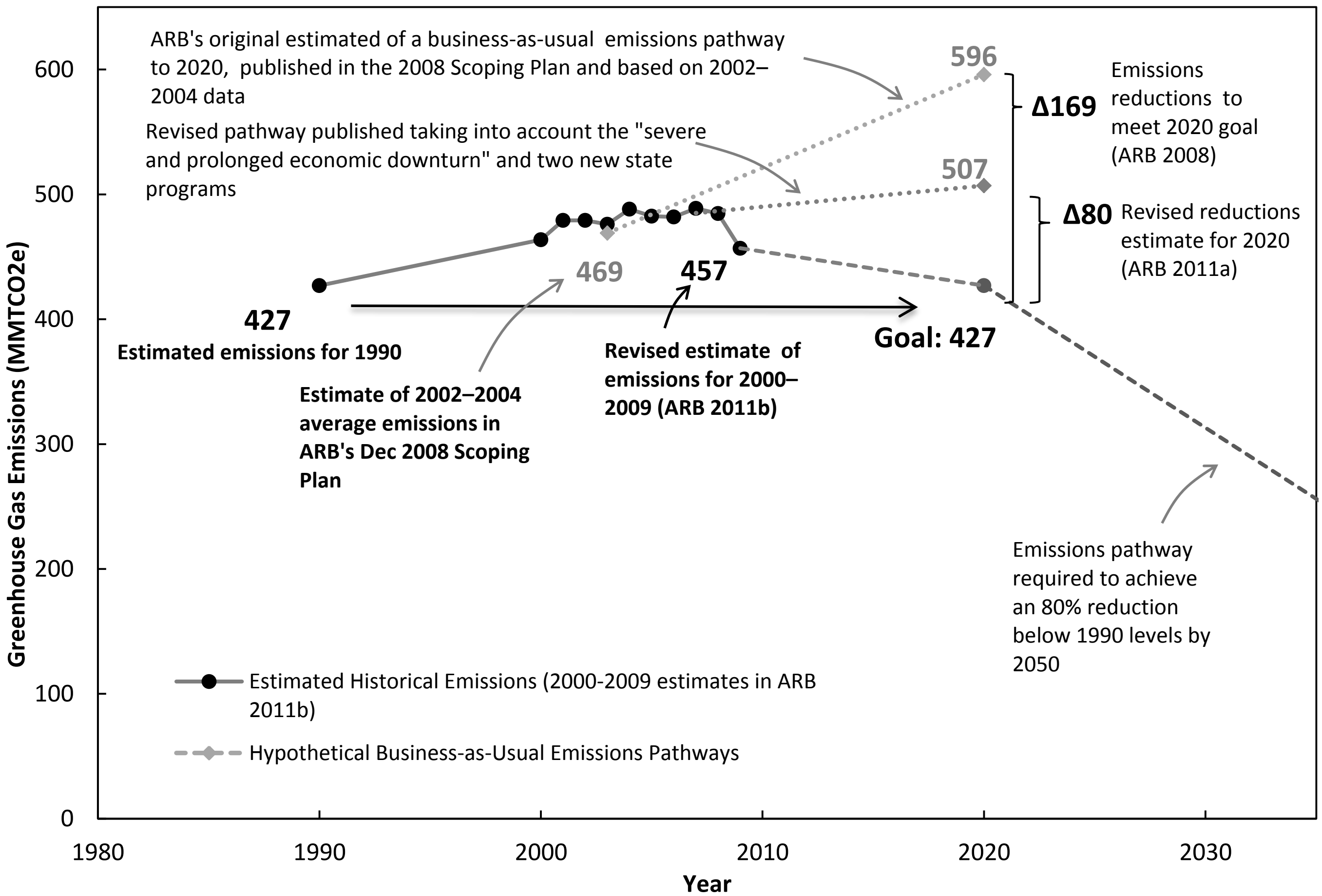

Figure 4. California's Projected Greenhouse Gas Emissions in 2020 and Planned Reductions
Sources: ARB 2008; ARB 2011a; ARB 2011b

By 2009, however, growth and emissions had stalled due to a severe and prolonged economic downturn. Furthermore, the state adopted two new policies that would limit future emissions growth: the Pavley Clean Car Standards (AB 1493, 2009) and the Renewables Portfolio Standard (expanded by SB 2 in 2011). In 2011, ARB published revisions to the 2020 GHG emissions reduction targets based on emissions estimates for 2006-2008, which had declined to 457 MMTCO$_2$e (ARB 2008). Thus, the state's emissions reduction targets were smaller than those deemed necessary just three years earlier (80 MMTCO$_2$e compared to 169 MMTCO$_2$e). The planned emissions reductions pathways are summarized in Figure 4. Nearly every sector of the economy has come under scrutiny, with a particular emphasis on those sectors that are the most polluting, such as transportation and oil refineries.

While there are no mandated emissions reductions for the water sector, an estimated reduction of 4.8 MMTCO$_2$e from the sector is included under "other recommended measures" from ARB (Table 4). These estimates were developed by the Water-Energy Team of the Climate Action Team (WET-CAT), which is made up of staff from various state agencies, including the Department of Water Resources (DWR), State Water Resources Control Board, California Energy Commission, and California Public Utilities Commission. ARB noted that these reductions are mostly in electric use and may be counted elsewhere in the scoping plan, but that "a portion of these reductions will be additional to identified reductions in the Electricity sector" and that ARB is working closely with appropriate agencies to refine these estimates (ARB 2008, 66).

The water sector is a large energy user in California. As described previously, about 19% of the state's electricity use and 33% of the state's non-electricity natural gas consumption is water related. Water managers are increasingly aware of the risks associated with climate change, and there appears to be a strong desire in the sector (at least at the state level and among some large municipal utilities, such as the East Bay Municipal Utilities District, Sonoma County Water Agency, and Inland Empire Utilities Agency) to increase efficiency and reduce emissions. DWR, which operates the State Water Project, a large system of dams, canals, pipelines, and pumps that delivers water to cities and farms in the Central Valley and Southern California, is the single largest user of energy in the state. DWR plans to reduce its emissions, which peaked at 4.1 $MMTCO_2e$ in 2003, to 1.65 $MMTCO_2e$ by 2020 through a variety of actions, including phasing out coal power (Schwarz 2012).

Table 4. Planned Greenhouse Gas Emissions Reductions by California's Water Sector, from ARB's 2008 Scoping Plan

Measure	Reduction ($MMTCO_2e$)
Water Use Efficiency	1.4
Water Recycling	0.3
Water System Energy Efficiency	2.0
Reuse Urban Runoff	0.2
Increase Renewable Energy Production	0.9
Public Goods Charge	TBD
Total	4.8

Source: ARB 2008

Potential Emissions from Desalination

As noted earlier, desalination is among the most energy-intensive source of water in California. Producing a million gallons of desalinated seawater requires an average of 15,000 kWh (4.0 kWh/m^3), considerably more than other water supply and treatment options available in California. We have estimated the theoretical potential emissions that could occur if all of the currently proposed desalination plants are eventually built. Overall, we estimate that expanding the state's seawater desalination capacity by 514 million gallons per day (MGD) would increase energy use by about 2,800 GWh per year.[6] To put this in perspective, the total electricity use in California in 2011 was 270,000 GWh (CEC 2012). Thus, desalination build-out would represent about a 1% increase above current electricity use.

If we assume that all of the desalination plants are powered by the electricity grid, we estimate that the build-out of the currently proposed desalination plants would lead to emissions of about 1.0 $MMTCO_2e$ annually (Table 4), a 0.2% increase in the state's current emissions.[7] The potential emissions increase from build out of the desalination plants alone is equivalent to about one-fifth of the planned *reductions* in the water sector identified in the 2008 AB 32 Scoping Plan (4.8 $MMTCO_2e$). Additionally, introducing a new source of water increases the amount of water that must be delivered to customers, used in homes and businesses, collected, treated again as wastewater, and discharged – all of which use energy and result in GHG emissions. This increase in emissions is antithetical to the state's directive to reduce GHG emissions.

[6] Based on an energy requirement of 15,000 kWh/MG.

[7] Potential desalination-related emissions are calculated based on 2009 emissions factors.

Table 5. Theoretical Emissions Associated with Proposed Desalination Plants in California

Project Partners	Location	Capacity (MGD)	Energy Use (MWh per day)	Emissions (MMT CO_2e per yr)
East Bay Municipal Utilities District, San Francisco Public Utilities Commission, Contra Costa Water District, Santa Clara Valley Water District, Zone 7 Water Agency	Pittsburg	19.8	300	0.03
City of Santa Cruz, Soquel Creek Water District	Santa Cruz	5	75	0.007
DeepWater, LLC	Moss Landing	2.5	38	0.003
The People's Moss Landing Water Desal Project	Moss Landing	25	380	0.03
California American Water	North Marina	10	150	0.01
California Water Service Company	Not known	9	140	0.01
Ocean View Plaza	Monterey	0.25	3.8	0.003
Monterey Peninsula Water Management District	Del Monte Beach, Monterey	2	30	0.0003
Seawater Desalination Vessel	Monterey Bay	20	300	0.06
Cambria Community Services District/U.S. Army Corps of Engineers	Cambria	0.6	9.0	0.0008
Arroyo Grande, Grover Beach, Oceano Community Services District	Oceano	2	30	0.003
West Basin Municipal Water District	El Segundo	18	270	0.03
Poseidon Resources	Huntington Beach	50	750	0.08
Municipal Water District of Orange County, Laguna Beach County Water District, Moulton Niguel Water District, City of San Clemente, City of San Juan Capistrano, South Coast Water District	Dana Point	15	230	0.03
City of Oceanside	City of Oceanside	10	150	0.02
Poseidon Resources, San Diego County Water Authority	Carlsbad	50	750	0.09
San Diego County Water Authority	Camp Pendleton	150	2,300	0.3
NSC Agua	Rosarito, Mexico	100	1,500	0.08
San Diego County Water Authority	Rosarito, Mexico	25	380	0.3
	TOTAL	**514**	**7,700**	**1.0**

Note: Based on an energy intensity of desalination equal to 15,000 kWh per million gallons (4.0 kWh/m^3). Emissions factors for regional utilities from the California Climate Registry (ARB 2010). Numbers may not add up due to rounding.

We note that the proposed desalination facilities may replace, to some extent, existing water supply and treatment facilities. In other words, they may not all be "additional" to existing water supply systems, and some of the GHG emissions included in the estimate above may already be occurring. Additionally, as renewables are added to California's grid, emissions may decrease over time. Thus, while we can analyze the potential effects of desalination build out, the precise amount of future electricity use and emissions depends on a number of factors that are difficult to quantify.

Regulatory Framework

The California Environmental Quality Act

The California Environmental Quality Act, or CEQA, is the State's premiere environmental law, requiring that "state and local agencies disclose and evaluate the significant environmental impacts of proposed projects and adopt all feasible mitigation measures to reduce or eliminate those impacts" (California Department of Justice 2012). The law, as enacted in 1972, contained no provisions specifically related to climate change or carbon emissions. In 2007, however, state lawmakers passed SB 97, directing the Natural Resources Agency to adopt amendments to the CEQA guidelines to address greenhouse gases. These are now codified in state law, as part of California's Code of Regulations, Title 14: Natural Resources Law (Natural Resources Agency 2009). Agencies have always been required under CEQA to identify significant environmental impacts and adopt all feasible measures to mitigate (or lessen) those impacts.[8] Henceforth, project applicants are expressly required to analyze GHG emissions during the CEQA process.

The issue of cumulative impacts of pollutants, including GHG emissions, has been argued in the courts for years. When faced with a global environmental problem, project applicants could reasonably state that their emissions were so small that they represent a *de minimis* source of pollution and therefore should not be regulated. However, while individual polluters may cause little harm on their own, their cumulative impacts can be significant. State and national environmental laws are designed to protect natural resources from the cumulative effects of pollutants. The courts have begun to recognize this, and recent rulings have eroded the *de minimis* argument. For example, a federal court ruled in 2008 that "the impact of greenhouse gas emissions on climate change is precisely the kind of cumulative impacts analysis that the National Environmental Protection Act requires agencies to conduct" (cited in Baldwin 2008, 792).

The State CEQA Guidelines (2012, Section 2109) require "lead agencies" to evaluate the GHG emissions of a proposed project.[9] Additional guidance is provided by the Governor's Office of Research and Planning (OPR): "Lead agencies should make a good-faith effort, based on available information, to calculate, model, or estimate the amount of CO_2 and other GHG emissions from a project, including the emissions associated with vehicular traffic, energy consumption, water usage, and construction activities." Lead agencies must also reach a conclusion regarding the significance of a project's emissions (OPR 2012) and describe how they will mitigate significant emissions.

State regulators realized that including GHG emissions in CEQA could hold up or derail nearly

[8] The word *mitigation* can cause some confusion, as it has different meanings in the climate change community and in CEQA practice. When discussing CEQA, mitigation refers to measures to avoid or substantially reduce a project's significant environmental impacts.

[9] The lead agency is the government agency which has the discretion to approve or deny a project and is responsible for producing the CEQA analysis. A project applicant is often not the same entity as the lead agency. The applicant is the entity that wants to develop a project.

any project. To avoid this, the State CEQA Guidelines, as revised in 2010, allow lead agencies to create *programmatic* greenhouse gas reduction plans that cover all resources within the agency's jurisdiction, rather than dealing with the emissions from projects individually (Schwarz 2012, 17). In other words, the agency could analyze the total emissions that will result from or be influenced by all of its future activities in aggregate. If an individual project is consistent with the regional plan, then its GHG emissions will not be flagged as a significant impact.

Appendix G of the State CEQA Guidelines includes sample questions for evaluating project impacts. The two questions applicable to a project's climate-change-related impacts are:

- Would the project generate greenhouse gas emissions, either directly or indirectly, that may have a significant impact on the environment?
- Would the project conflict with an applicable plan, policy, or regulation adopted for the purpose of reducing the emissions of greenhouse gases?

Kerr (2012) reports that there are three basic types of thresholds that lead agencies may select for determining significance:

- mass emission thresholds;
- efficiency-based thresholds; or
- consistency with an adopted plan.

One mass emission threshold that some lead agencies have used is 10,000 metric tonnes of CO_2e per year, which is the level at which individual stationary sources are required to quantify and report their GHG emissions to the California Air Resources Board ARB. Other lead agencies have used a mass emission threshold of 25,000 metric tonnes of CO_2e per year, the level at which most stationary sources are required to participate in the State's Cap and Trade Program. Examples of efficiency-based metrics include the GHG intensity of the water produced by a desalination facility expressed in units of metric tonnes of CO_2e per million gallons or metric tonnes of CO_2e per customer served. Under a "consistency approach," the lead agency determines whether the project is consistent with a local Climate Action Plan, for example, by demonstrating whether a proposed project would interfere with planned region-wide emissions reductions.

Some regional agencies have recommended or adopted numeric significance thresholds for evaluating GHGs. For example, the South Coast Air Quality Management District issued rules in December 2008, creating a two-step method for determining whether a project's emissions are deemed "significant" under CEQA. First, if a project's emissions exceed the GHG budgets in an approved regional plan, then the lead agency must look at numerical thresholds created by the Air District. The project's emissions are deemed significant if emissions exceed (after mitigation) the following screening levels:

- 10,000 metric tonnes of CO_2e per year for industrial projects; or
- 3,000 metric tonnes of CO_2e per year for commercial or residential projects.

The threshold for commercial and residential projects is equivalent to the emissions from about 230 average American homes (Jones and Kammen 2011).

Here is how this might work in practice. Suppose a Southern California community has created an emissions reduction plan and its goal is to reduce GHG emissions to 1990 levels by 2020. This plan allows for 1,000 new housing units and includes emissions reduction measures through land use and transportation planning, energy efficiency programs, and purchasing renewable energy. In this community, a proposal for a new 500-unit subdivision, if it is otherwise compatible with the plan, could be approved more quickly and its CO_2 emissions would not be flagged as "significant" during CEQA review. In a community without an approved emissions reduction plan, the lead agency would need to determine whether GHG emissions associated with the proposed subdivision are significant and support its conclusion with substantial evidence. If the lead agency determined that GHG emissions associated with the proposed subdivision would be significant, then all feasible mitigation measures must be implemented to reduce the impact to a less-than-significant level.

California Coastal Commission

The California Coastal Commission is charged with protecting the ocean environment off of California's shores, and obtaining a Coastal Development Permit from the Commission is one of the key regulatory approvals for a new desalination plant. The Coastal Commission looks at many factors when considering issuing this permit, including greenhouse gas emissions. Staff of the Coastal Commission has noted that "desalination is a relatively energy-intensive water source, and depending on a facility's source of electricity, it may result in relatively high indirect greenhouse gas emissions, which further exacerbate the ocean acidification process" (Luster 2011).

GHG emissions have not yet been a major issue with the Coastal Commission. For Poseidon's 50 MGD plant in Carlsbad, the largest desalination plant that has been permitted in California, the applicant voluntarily developed an energy minimization and greenhouse gas emissions reduction plan, which is discussed further below. The Coastal Commission, however, did not require GHG reduction or mitigation from the newest desalination plant in California, the 0.6 MGD plant built in Sand City in 2010. Nonetheless, the plant's designers have taken steps to maximize its energy efficiency, but managers have not chosen to purchase renewable energy or carbon offsets (Sabolsice 2013). This is an emerging issue, however, that may factor into the debate over future coastal permits.

Integrated Regional Water Management Planning Guidelines

In 2002, the California legislature passed the Integrated Regional Water Management Act (SB 1672) "to encourage local agencies to work cooperatively to manage local and imported water supplies to improve the quality, quantity, and reliability" (DWR 2012a). The IRWM program is administered largely by DWR, with support from the State Water Resources Control Board. Under this program, local governments, utilities, watershed groups, and other interested parties develop an Integrated Regional Water Management Plan (IRWMP). Subsequent legislation made funding available to regional bodies to support planning activities, including $380 million from Proposition 50 in 2002 and $1 billion from Propositions 84 and 1E in 2006. Further legislation in 2008 (SB1, the IRWM Planning Act) provided a general definition of an IRWM plan and guidance on what IRWM program guidelines must contain. Today, there are 48 IRWM regions in the state, bringing together a variety of stakeholder groups to develop IRWM plans.

In 2010, the state created new requirements for IRWM regions to assess climate change vulnerability and consider greenhouse gas emissions as a part of the planning process. DWR released revised IRWM Guidelines in 2010 and again in 2012, which include climate change as one of 16 "standards" that must be included in IRWM plans in order to receive planning and implementation funds from state grant programs. According to these guidelines, IRWM plans must include both *mitigation* and *adaptation* strategies.[10] In practice, this means that planners should include a greenhouse gas emissions inventory for all aspects of the region's existing and planned water system, including as much detailed and quantitative data as is feasible given time, expertise, and financial resources. In addition, IRWM plans must include "a process that

[10] In the climate change literature, *mitigation* refers to efforts to reduce greenhouse gas emissions, while *adaptation* refers to strategies to deal with climate change impacts.

considers GHG emissions when choosing between project alternatives" (DWR 2012b, 23). While GHG emissions must be considered, the guidelines do *not* state that lower-emission alternatives must be chosen, or even given preference.

In an effort to promote compliance with the new guidelines, DWR, the Environmental Protection Agency, and the US Bureau of Reclamation developed the *Climate Change Handbook for Regional Water Planning* (Schwarz et al. 2011). According to these guidelines, planners must consider GHG emissions reduction in the project-review process, but as a "secondary criterion" (p 72). To be eligible for state funding, all projects must have an analysis of GHG emissions which must be quantitative, and the guidelines suggest several analytical tools for performing the analysis. Regions must also join the California Climate Action Registry, an organization that catalogs and tracks GHG emissions for businesses and governments in the state.

A recent review of the program studied how climate change is being addressed during the planning process (Conrad 2012). Conrad found that only about a third of the plans created before the new 2010 guidelines included a discussion about climate change. In more recent plans, the level of detail varies, as does the approach; however, all regions stated that they would consider GHG emissions in project selection. Thus, state water management agencies have expressed their preference for reduced emissions among all water projects in the state and directed local decision makers to consider making reductions, although they have not yet established a specific mandate or targets for local or regional water projects.

Greenhouse Gas Emissions Reduction Strategies

There are several ways to reduce the greenhouse gas emissions associated with desalination plants. These include (1) reducing the total energy requirements of the plant; (2) powering the desalination plant with renewable energy; and (3) purchasing carbon offsets. Energy reduction strategies are described on page 8 of this report. Here, we describe strategies for powering desalination plants with renewables and purchasing carbon offsets as a means of reducing GHG emissions.

Renewable Energy Sources

Some desalination proponents have pointed to the possibility of running desalination plants with alternative energy systems, from solar to nuclear, as a way of reducing dependence on fossil fuels and reducing greenhouse gas emissions and their contribution to climate change. Indeed, solar energy has been used for over a century to distill brackish water and seawater. The simplest example of this process is the greenhouse solar still, in which saline water is heated and evaporated by incoming solar radiation in a basin on the floor, and the water vapor condenses on a sloping glass roof that covers the basin. One of the first successful solar systems was built in 1872 in Las Salinas, Chile, an area with very limited freshwater. This still covered 4,500 square meters, operated for 40 years, and produced over 5,000 gallons of freshwater per day (Delyannis and Delyannis 1984). Variations of this type of solar still have been tested in an effort to increase efficiency, but they all share some major difficulties, including large land area requirements, high capital costs, and vulnerability to weather-related damage.

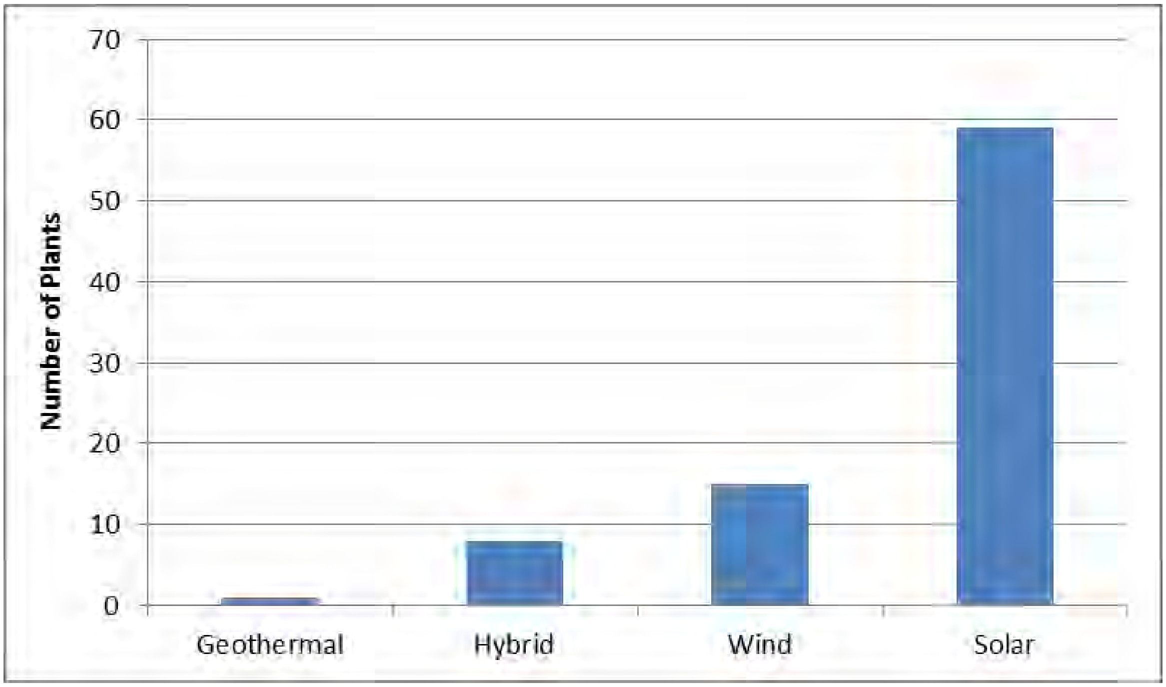

Figure 5. Global Renewable Energy Seawater Desalination Plants by Energy Source, 2010
Source: ProDes 2010

In addition to solar stills, there are several other ways to couple desalination plants with renewable energy, either directly or indirectly.[11] Plants directly powered by renewables have a dedicated renewable energy source whereas those indirectly powered by renewables draw power from an electricity grid that includes renewables. Interest in *directly* powering desalination plants with renewables is growing, although most plants built to date are small demonstration plants. Since 1974, an estimated 132 renewable-energy desalination plants, with a combined capacity of less than 1 MGD (3,600 m^3/d), have been installed worldwide (ProDes 2010). Energy sources for these systems include geothermal energy, wind, solar thermal, and solar photovoltaic. Seawater desalination represented 63% of the total number of plants powered by renewables and 86% of the total renewable energy desalination capacity. As shown in Figure 5, the overwhelming majority of these seawater desalination plants use solar power, in part because it is a more reliable energy source than wind in most areas (World Bank 2012). The largest of the renewable desalination plants, however, are powered by wind, which tends to be less expensive than solar photovoltaic.

Powering desalination plants directly by renewables faces several challenges, one of the biggest of which is the availability of sufficient energy where and when it is needed. Desalination plants, especially those using membrane technologies, require a continuous source of energy. Solar and wind energy, however, are subject to daily and seasonal fluctuations. Geothermal energy is more consistent; however, it is only available in certain areas. While there are means for storing renewable energy, such as pumping water into hilltop reservoirs and recovering the energy with hydroelectric generators or storing excess heat in associated thermal storage systems that can later be converted to electricity, these storage systems have not yet been employed on a large scale.

[11] Although there is interest in powering desalination plants with nuclear energy in some parts of the world, we do not discuss that here given strong opposition to nuclear and bans on the development of new nuclear reactors in California.

Desalination plants can also be indirectly powered by renewables by increasing the amount of renewable energy supply to the grid, relative to the needs of the desalination facility. With this approach, the plant developer would construct or fund the construction of renewable energy plants (on- or off-site) to feed energy into the same electricity grid to which the desalination plant is connected. Supporters say that this approach is generally simpler and more flexible than building dedicated renewables, as it taps into existing markets for renewable energy and the infrastructure is already in place to deliver the electricity where it is needed. Furthermore, grid electricity is always on, as opposed to more intermittent sources like wind and solar.

This approach has been widely used in Australia through the purchase of Renewable Energy Certificates (RECs). In Australia, an REC, which represents 1 megawatt-hour of electricity generated from a renewable energy source, can be sold and traded or bartered. The funds received from the sale of RECs are intended to allow renewable energy companies to cover the higher cost of generating renewables. Several large-scale desalination facilities in Australia have purchased RECs from new offsite renewable energy projects (Box 3). In order for these plants to be completely carbon neutral, however, the purchase of RECs must offset all of the energy required by the facility and must result in *new* sources of renewable energy. RECs for existing or planned facilities would not serve to offset the emissions from the desalination facility since the renewable energy would have been generated with or without the desalination plant. Although energy users purchase RECs from specific renewable energy projects, it is often difficult to confirm whether new renewable energy projects were built because the desalination plants purchased their certificates or whether the projects would have been built anyway.

Carbon Offsets

In addition to reducing GHG emissions though energy efficiency measures or investing in renewables, project developers may also purchase *carbon offsets* to mitigate GHG emissions. The idea behind offsets is to pay someone else to reduce their emissions to "cancel out" your own emissions. Today, there is an international market in carbon offsets, with thousands of buyers and sellers. There is also a wide variety in the price and type of offsets. Some offset providers invest in renewable energy, such as wind, solar, hydroelectric, or biofuels; the concept is that these new energy sources will reduce consumption of fossil fuels. Other offset sellers engage in projects that are meant to reduce greenhouse gas emissions. For example, an offset project may help a hog farmer to install a system to capture methane from animal waste. Or it may help a factory in a developing country to install emissions controls to prevent the release of potent greenhouse gases, such as hydrofluorocarbons and perfluorocarbons. Yet another class of offsets is designed to prevent deforestation or land degradation, which includes schemes called REDD (Reducing emissions from deforestation and forest degradation).

With the exception of DWR, California water suppliers are not currently regulated under AB 32, and thus desalination proponents that pursue this option would be purchasing *voluntary* offsets. Under California's emissions reduction scheme, regulated entities are allowed to purchase offsets to fulfill up to 8% of their required emissions reductions. For companies to obtain credit toward their required reductions, the offsets they purchase must be certified by ARB. At present, ARB has stated that it will certify only certain types of domestic offsets, while considering expanding the program in the future. Voluntary offsets, on the other hand, can be purchased from any number of private companies, or from clearinghouses that are part of emissions trading programs, such as Europe's Clean Development Mechanism (CDM).

Outside of the regulated offset market, the price of private offsets varies greatly, with prices in 2012 ranging from $0.50 to $30 per metric tonne of CO_2. The quality of offsets also appears to vary greatly. Under the CDM -- Europe's experiment with carbon offsets -- there have been many poorly designed projects and some cases of outright fraud (McCully 2008). In response, scholars and regulators have developed a number of concepts to verify the quality of offsets. California regulators, for example, have drawn on international experience and scholarship and created rules stating that regulated offset allowances must "represent a GHG emission reduction or GHG removal enhancement that is *real, additional, quantifiable, permanent, verifiable, and enforceable*" (ARB 2012). These criteria capture how difficult it can be to ensure that promised emissions reductions are tangible and would not have otherwise occurred without the influence of the offset project.

For example, an offset may pay a subsidy to a company for solar energy to make it more attractive to the buyer, compared to conventional fossil fuel sources. However, would the company have purchased solar anyway, without the subsidy? The burden is on the offset provider to prove that its investment resulted in "additional" emissions reductions that would not have happened without are uncontrolled or uncounted? For example, will protecting a plot of rainforest from agricultural development simply result in another piece of land being clear-cut and converted to farming? And will that forest be protected in perpetuity? Given all of these questions, it can be difficult to prove that offsets will prduce meaningful long-term emissions reductions.

Offsets have been criticized on other grounds as well. English environmentalist and writer George Monbiot has likened offsets to indulgences granted by churches in the Middle Ages, as they allow polluters to continue with business as usual by simply making payments. He argues that the system of offsets "persuades us we can carry on polluting" and delays the changes necessary to slow climate change (Monbiot 2006).

Further, because of the proliferation of companies selling offsets and the lack of regulation in the voluntary market, there is evidence that "many offset reduction claims are exaggerated or misleading" and even cases of outright fraud (Carbon Offset 2013). Forestry projects under REDD have been particularly controversial, and several cases of human rights abuses have been documented. In Uganda, Oxfam International described a case where 20,000 farmers were evicted from their land, without notification or adequate compensation, to make room for a tree plantation offset project by the London-based New Forests Company (Grainger and Geary 2011). In Brazil, indigenous leaders opposing projects that would force their communities off of ancestral land have been harassed by authorities and received death threats (Goldtooth and Conant 2012).

Carbon offsets have been welcomed by politicians and regulators in California, who expect them to play a part of the state's emissions reductions goals. However, caution is required when purchasing offsets, particularly on the voluntary market, to ensure that they are effective, meaningful, and do no harm. A commitment to go "carbon neutral" is laudable. Companies, however, should commit to purchasing high-quality offsets from certified sources, and independent parties should verify these claims.

Box 3. Seawater Desalination Plants Powered by Renewables in Australia

In 2001, the Australian federal government implemented the Mandatory Renewable Energy Target, which now requires that renewable energy make up 20% of Australia's electricity mix by 2020. Victoria and New South Wales have also created state-level renewable energy targets. In Australia, desalination plants can offset their energy needs by purchasing Renewable Energy Certificates (RECs) equivalent to the amount of electricity consumed. Below are details on several large-scale desalination facilities that have purchased RECs from new offsite renewable energy projects.

Kwinana Seawater Desalination Plant (Western Australia)

The Kwinana Seawater Desalination Plant is located near Perth in Western Australia and was completed in late 2006. The 38 MGD (130 megaliters per day) plant produces water for the Perth metropolitan area. Plant operators purchase electricity generated by the Emu Downs Wind Farm, which is located 120 miles north of Perth. The wind farm consists of 48 wind turbines and contributes more than 272 GWh per year into the grid, fully offsetting the estimated 180 GWh per year required by the desalination plant (Sanz and Stover 2007).

Tugun Desalination Plant (Southeast Queensland)

The Tugun Desalination Facility is located along the Gold Coast in Southeast Queensland. The 33 MGD (125 megaliters per day) plant was completed in February 2009. At full production, the plant consumes about 150 GWh per year (WaterSecure n.d.). The plant's energy use is offset by the purchase of RECs, with solar hot water systems providing the main source of energy, followed by solar photovoltaic, hydropower, and a small amount of wind (WaterSecure 2009). The desalination plant was put on standby in December 2010 due to high operating cost and operational issues (Marschke 2012).

Kurnell Desalination Plant (New South Wales)

The Kurnell Desalination Plant is located near Sydney in New South Wales. The 66 MGD (250 megalitres per day) plant was completed in early 2010. The plant operators purchased RECs from the 140 MW Capital Wind Farm near Bungendore. The wind farm was built specifically to supply power to the desalination plant but provides additional energy to the grid (Infigen Energy n.d.). The desalination plant was put in stand-by mode in July 2012 due to the availability of less expensive water supply alternatives (AAP News 2012).

(continued on next page)

Box 3. Seawater Desalination Plants Powered by Renewables in Australia (continued)

Southern Seawater Desalination Plant (Western Australia)

The Southern Seawater Desalination Plant is located in Western Australia and was completed in August 2011. Expansion of the facility, which is expected to be completed in 2013, will double the capacity of the plant to 72 MGD (270 megaliters per day) (Water Corporation n.d.a). The plant operators will purchase the entire output of two new renewable energy projects: the 55MW Mumbida Wind Farm and the 10MW Greenough River Solar Farm (Water Corporation n.d.b). The electricity produced by these projects will be fed into Western Power's grid, which then provides the electricity required for the desalination plant, and will offset all of the energy required by the desalination plant.

Wonthaggi Desalination Plant (Victoria)

The Wonthaggi Desalination Plant, located in Victoria, was fully operational in late 2012. All the power required to operate the 109 MGD (410 megaliters per day) desalination plant and distribution pipeline will be fully offset by RECs, which support the development of the Oaklands Hill wind farm (63 MW); the Macarthur wind farm (420 MW); and several other renewable energy projects. Upon completion, the desalination plant was quickly put on standby due to lack of demand (Hosking 2012).

Port Stanvac Desalination Plant (Southern Australia)

The Port Stanvac Desalination Plant, located near Adelaide in Southern Australia, is under construction. The 72 MGD (270 megaliters per day) plant will be powered by renewables through the purchase of RECs. The plant is expected to be completed in 2013 but in an October 2012 statement, SA Water Chief Executive John Ringham announced that "to keep costs down for our customers, SA Water is planning to use our lower-cost water sources first, which will mean placing the desalination plant in stand-by mode when these cheaper sources are available" (Kemp 2012). The desalination plant, which cost nearly $1.9 billion, is slated to go on stand-by mode in 2015. Plant operators will be required to pay a minimum amount each year while the project is in standby, although they will not reveal how much due to commercial confidentiality arrangements (Kemp 2012).

Going Carbon Neutral in California?

In the absence of state or local mandates, desalination proponents in California may voluntarily commit to carbon neutrality, which requires balancing the amount of carbon released with an equivalent amount sequestered or offset. That approach, however, can be controversial. An interesting example is provided by the 50 MGD desalination plant proposed in Carlsbad by Poseidon Resources. Poseidon claims carbon reductions through a range of activities (Voutchkov 2008). The largest of these is carbon emission reduction tied to reduced water imports from the State Water Project, responsible for about 70% of the carbon budget. They argue that San Diego has in recent years imported 90% of its water supply from outside the region, which takes energy to pump and treat and results in GHG emissions. And while the desalinated water will take even more energy, and cause more emissions, Poseidon argues it is only responsible for offsetting the *difference* between these two, or the additional energy caused by desalination compared to imported water. Poseidon proposes to mitigate the remaining 30% of the emissions from the desalination plant through a variety of means, including energy recovery devices, solar panels on the roof, green building design, fuel-efficiency standards, and by purchasing carbon offsets.

Some groups have criticized Poseidon's approach, including the San Diego Coastkeeper and the Planning and Conservation League (San Diego Coastkeeper 2010, Minton 2010). The first issue is whether Poseidon should be responsible for offsetting all of its emissions, or only its "net" emissions that take into account reduced water imports. Some have argued that "the Carlsbad plant will produce new water, and that taking emission credit for reduced water imports should not be permitted in a greenhouse gas reduction plan" (Heede 2008). While San Diego County Water Authority staff has publicly stated that water from the desalination plant would reduce the amount of imported water purchased from the Metropolitan Water District (Weinberg 2013), there is no binding legal agreement to ensure that this occurs. But even if imports are reduced, the project proponents state that this would reduce the amount of water imported from the *State Water Project*, the most energy intensive imported water source in the region. In reality, reductions of imported water would likely be a combination of water from the State Water Project and the less energy- and carbon-intensive Colorado River Aqueduct.

In an analysis commissioned by the San Diego Coastkeeper, the consultancy Climate Mitigation Services (CMS) found that Poseidon overestimated their potential GHG reductions and underestimated the amount of offsets it would need to purchase to achieve net zero emissions (Heede 2008). CMS raised several concerns about Poseidon's analysis, including assumptions about displaced imports (described on previous page), electricity emissions factors, and motor efficiency ratings. But even accepting the displaced imported water argument, CMS estimated that the number of offsets needed would equal 53,000 MMTCO_2e per year, significantly higher than Poseidon's estimate of 16,000 MMTCO_2e per year. Assuming an average offset cost of $8 per MMT$CO_2$e, Poseidon may have underestimated the annual cost of purchasing offsets by around $300,000.[12]

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[12] In 2012, each offset could be purchased for between $4 (for wind farms in China) to $120 (for "gold standard" domestic projects) (Peters-Stanley 2013).

4 Conclusions

Removing the salt from seawater is an energy-intensive process and consumes more energy per gallon than most other water supply and treatment options. On average, desalinations plants use about 15,000 kWh per million gallons of water produced (kWh/MG), or 4.0 kWh per cubic meter (kWh/m^3). We note, however, that these estimates refer to the rated energy use, i.e., the energy required under a standard, fixed set of conditions. The actual energy use may be higher, as actual operating conditions are often not ideal.

The overall energy implications of a seawater desalination project will depend on whether the water produced replaces an existing water supply or provides a new source of water for growth. If water from a desalination plant replaces an existing supply, then the additional energy requirements are simply the difference between the energy use of the seawater desalination plant and those of the existing supply. Producing a new source of water, however, increases the total amount of water that must be delivered, used, and disposed of. Thus, the overall energy implications of the desalination project include the energy requirements for the desalination plant plus the energy required to deliver, use, and dispose of the water that is produced. We note that conservation and efficiency, by contrast, can help meet the anticipated needs associated with growth by reducing total water demand while simultaneously maintaining or even reducing total energy use.

Energy requirements for desalination have declined dramatically over the past 40 years due to a variety of technological advances, and desalination designers and researchers are continuously seeking ways to further reduce energy consumption. Despite the potential for future energy use reductions, however, there is a theoretical minimum energy requirement beyond which there are no opportunities for further reductions. Desalination plants are currently operating at 3-4 times the theoretical minimum energy requirements, and despite hope and efforts to reduce the energy cost of desalination, there do not appear to be significant reductions in energy use on the near-term horizon.

The high energy requirements of seawater desalination raise several concerns, including sensitivity to energy price variability. Energy is the largest single variable cost for a desalination plant, varying from one-third to more than one-half the cost of produced water (Chaudhry 2003). As result, desalination creates or increases the water supplier's exposure to energy price variability. In California, and in other regions dependent on hydropower, electricity prices tend to rise during droughts, when runoff, and thus power production, is constrained and electricity demands are high. Additionally, electricity prices in California are projected to rise by nearly 27% between 2008 and 2020 (in inflation-adjusted dollars) to maintain and replace aging transmission and distribution infrastructure, install advanced metering infrastructure, comply with once-through cooling regulations, meet new demand growth, and increase renewable energy production (CPUC 2009). Rising energy prices will affect the price of all water sources, although they will have a greater impact on those that the most energy intensive.

It is important to note that water from a desalination plant may be worth more in a drought year because other sources of water will be limited. Thus, building a desalination plant may reduce a water utility's exposure to water reliability risks at the added expense of an increase in exposure to energy price risk. Project developers may pay an energy or project developer to hedge against this uncertainty, e.g., through a long-term energy purchase contract or through on-site energy production from sources with less variability, such as solar electric. The hedging options, however, may increase the overall cost. In any case, energy price uncertainty creates costs that should be incorporated into any estimate of project cost.

The high energy requirements of seawater desalination also raise concerns about greenhouse gas emissions. In 2006, California lawmakers passed the *Global Warming Solutions Act*, or Assembly Bill 32 (AB 32), which requires the state to reduce greenhouse gas emissions to 1990 levels by 2020. Thus, the state has committed itself to a program of steadily reducing its greenhouse gas emissions in both the short- and long-term, which includes cutting current emissions and preventing future emissions associated with growth. Action and awareness has, until recently, been uneven and slow to spread to the local level. While the state has directed local and regional water managers to begin considering emissions reductions when selecting water projects, they were not subject to mandatory cuts during the state's first round of emissions reductions. As the state moves forward with its plans to cut carbon emissions further, however, every sector of the economy is likely to come under increased scrutiny by regulators. Desalination – through increased energy use – can cause an increase in greenhouse gas emissions, further contributing to the root cause of climate change and thus running counter to the state's greenhouse gas reduction goals.

While there is "no clear-cut regulatory standard related to energy use and greenhouse gas emissions," (Pankratz 2012) there are a variety of state programs, policies, and agencies that must be considered when developing a desalination project. These include environmental review requirements under the California Environmental Quality Act, the issuance of permits by the Coastal Commission, the Integrated Regional Water Management Planning process, and policies of other state agencies, such as the State Lands Commission and the State Water Resources Control Board. These agencies have increasingly emphasized the importance of planning for climate change and reducing greenhouse gas emissions. While none of these preclude the construction of new desalination plants, the state's mandate to reduce emissions creates an additional planning element that must be addressed.

There is growing interest in reducing or eliminating greenhouse gas emissions by powering desalination with renewables, directly or indirectly, or purchasing carbon offsets. In California, we are unlikely to see desalination plants that are directly powered by renewables in the near future. A more likely scenario is that project developers will pay to develop renewables in other parts of the state that partially or fully offset the energy requirements of the desalination plant. Offsets can also reduce emissions, although caution is required when purchasing offsets, particularly on the voluntary market, to ensure that they are effective, meaningful, and do no harm.

Powering desalination with renewables can reduce or eliminate the greenhouse gas emissions associated with a particular project. This may assuage some concerns about the massive energy requirements of these systems and may help to gain local, and even regulatory, support. But it is important to look at the larger context. Even renewables have a social, economic, and environmental cost, albeit much less than conventional fossil fuels. Furthermore, these renewables could be used to reduce existing emissions, rather than offset new emissions and maintain current greenhouse gas levels. Communities should consider whether there are less energy-intensive options available to meet water demand, such as through conservation and efficiency, water reuse, brackish water desalination, stormwater capture, and rainwater harvesting. We note that energy use is not the only factor that should be used to guide decision making. However, given the increased understanding of the risks of climate change for our water resources, the importance of evaluating and mitigating energy use and greenhouse gas emissions are likely to grow.

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